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Strandings of NE Atlantic gorgonians

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**Abstract**

1. Northeast coral gardens provide vital breeding and feeding habitats for fishes of conservation and commercial importance. Such habitats are increasingly at risk of destruction as a result of over fishing, surface ocean warming, acidification and marine litter.
2. A key cause for concern regarding the vulnerability of coral gardens to damage from any source is their slow growth rate, and thereby their ability to recover from damage. Hence protected areas are being put in place, which exclude the use of towed demersal fishing gear.
3. Citizen scientists observed that gorgonian corals (Pink Sea Fans) skeletons were stranding on beaches entangled in marine debris (sea fangles) across southwest England. Further, SCUBA divers reported that gorgonian corals were being caught up and damaged in lost fishing gear and other marine litter.
4. To determine the cause of the damage to coral gardens, sea fangles were collected and analysed.
5. The sea fangles were made up of a diverse range of litter from fishing and domestic sources, however, the majority comprised of fishing gear ($P<0.05$).
6. Marine Protected Areas can protect coral gardens from direct fishing pressure, but risks still remain from ghost fishing pressure, demonstrating the need for sources of litter into the environment to be reduced and existing litter removed.
7. The EU MSFD outlines targets for marine litter by 2020. This study highlights the importance of adhering to the MSFD and/or creating more ambitious regulation if the UK re-write existing legislation following BREXIT.

**Keywords**: Coral, reef, benthic, conservation, marine litter, ghost fishing

## Introduction

The northeast Atlantic has a highly diverse coral fauna (Roberts *et al*., 2009), and historical records show that the region used to have extensive scleractinian coral reefs, as well as gardens of cold-water alcyonaceans (leather corals), antipatharians (black corals), gorgonians (sea fans) and stylasterids (hydrocorals) (Hall-Spencer *et al.* 2007b). Drawings by Gosse (1860) brought international attention to the beauty and abundance of anthozoans in the region and cold-water corals have long fascinated marine biologists due to the high diversity of life associated with the habitats that they create (Le Danois, 1948). In this paper, evidence of recent damage to coral gardens globally is discussed, prompted by citizen scientist reports of strandings of gorgonians in southwest England in late 2014.

In shallow waters above the thermocline there have been increasing incidences of gorgonian disease in tropical and temperate waters (Hall-Spencer *et al*. 2007a; Kim, 2015), and marine heat waves have caused mass mortalities in gorgonian populations (Cerrano *et al.* 2000). The combined effects of stressors such as over-fishing, surface ocean warming, acidification and marine litter mean that the managers of maritime activities will need to be forward-thinking to protect cold-water coral habitats (Witherell & Coon, 2000; Bo *et al.* 2014; Jackson *et al*. 2014).

Where strong currents and hard substrata are available, gorgonians can form dense stands from shallow waters down to depths of >2000 m (coral gardens) (Yesson *et al*. 2012). These coral gardens increase habitat structural complexity and thereby contribute strongly to their biodiversity (Krieger & Wing, 2002; Ponti *et al*. 2016). Cold-water corals that are easily damaged by towed demersal fishing gear provide habitat for the feeding and breeding of commercially important fishes (Costello *et al.* 2005). The mounting evidence of impacts of bottom trawling on scleractinians shows that towed demersal fishing leaves behind smashed reef frameworks (Hall-Spencer *et al*. 2002; Clark *et al.* 2010). Fishing impacts on gorgonians have a less obvious legacy, although gorgonians are just as vulnerable to the use of towed demersal gear and can be a prominent component of the by-catch (Watling & Norse, 1998; Stone, 2006; Edinger *et al*. 2007; Bo *et al.* 2014). A main reason for concern over the vulnerability of coral gardens to damage from any source is their slow rate of growth, so protected areas are being put in place, which exclude the use of towed demersal fishing gear (Althaus *et al*. 2009; Hall-Spencer *et al*. 2009; Harter *et al.* 2009; Sheehan *et al*. 2013a&b).

There are 83 species of gorgonian corals described for the NE Atlantic, but the vast majority of these live below 200 m depth (Hall-Spencer *et al*. 2007b). Only one species, *Eunicella verrucosa* (Pallas, 1766), occurs in shallow waters off England. It is known locally as the 'Pink Sea Fan' and large colonies may be over 50 years old: although they may grow up to 10 cm in the first year, their growth rate then slows to around 1 cm per year (Wood, 2013). This species is characteristic of rocky reefs on open coasts, although the rock substrata may not always be obvious due to a thin sediment veneer (Sheehan *et al.* 2013b), where it provides habitat for the rare Sea Fan Anemone *Amphianthus dohrnii* (Koch, 1878), a sea slug called *Tritonia* *nilsohdneri* (Marcus Ev. 1983) and the gastropod *Simnia hiscocki* (Pennant 1777) (Wood, 2013) as well as three dimensional seabed structures within which fish shelter (Figure 1). In the 1960s-70s, *E. verrucosa* were collected for souvenirs and so this is now one of the few marine species protected from intentional damage (Wildlife and Countryside Act, 1981). It is also listed as 'Nationally Scarce' in the UK and listed as 'Vulnerable' on the International Union for Conservation of Nature and Natural Resources 'Red List' of threatened species (IUCN, 2015). Heavy demersal gear types, such as beam trawls and scallop dredges, are currently widely used in southwest England (Campbell *et al.* 2014) and so there have recently been localized bans on their use over coral gardens within key conservation areas of the region (Sheehan *et al.* 2013, Pikesley *et al.* 2016). Eno *et al*. (2001) found that *E. verrucosa* were resilient to potting so this, and other forms of static gear, are currently permitted within coral gardens off southwest England.

While exclusion of demersal towed gear has benefitted Pink Sea Fan populations (Sheehan et al. 2013a&b), dead Pink Sea Fans are still stranding around southwest England, entangled in marine debris, from here on referred to as sea fangles. A 'fangle' is something newly fashioned or a foolish innovation. It is suspected that protected Pink Sea Fans are still being fished through the process of ghost fishing. Ghost fishing is the process of marine organisms becoming entangled in lost fishing gear and is most commonly associated with birds and cetaceans (Matsuoka *et al*. 2005; Brown & Macfadyen, 2007). It appears, however, that Pink Sea Fans are not only being ghost fished by lost fishing gear but also by domestic marine litter. The present study arose when hundreds of sea fangles were washed up on strandlines at multiple locations around southwest England in the winter of 2014-15, a phenomenon first reported in 2006 (unpublished data). It should be noted, that sea fangle strandings are now observed every winter in southwest England. The 2016 sea fangle strandings have been observed from November around the north and south coast of Cornwall, southwest England (TW and EV *pers. obs*.). To identify the source and scale of the marine debris entangled around the Pink Sea Fans, sea fangles were collected from three locations (Newquay, Wembury, Chesil see Figure 2.) and analysed. It is impossible to determine from the stranded sea fangles whether they were ghost fished, or broken off by fishing, storms and/or SCUBA divers (Coma *et al*. 2004), however, the hypothesis that the majority of the source of the entangled debris was from fishing was tested. To provide further evidence to test whether the cause of the stranded sea fangles was ghost fishing, observations made by Seasearch SCUBA divers (a UK based organisation, which uses volunteers to survey sub-tidal habitats) of living sea fans entangled with marine debris are also included. An animation demonstrating the ghost fishing hypothesis can be viewed at https://www.youtube.com/watch?v=n9SsNb6cK7g

## Methods

*Study sites and laboratory processing*

In 2014, local naturalists and beachcombers sent in reports to Plymouth University of hundreds of washed-up Pink Sea Fans around southwest England. In response, bundles of marine debris entangled around Pink Sea Fans (sea fangles) were collected systematically from the strandline at each of the reported locations: Chesil Beach, Wembury and Newquay (Figure 2). The rocky reef habitats off each of these beaches have gardens of *E. verrucosa* coral colonies in the circalittoral zone at depths of >20 m (Pikesley *et al.* 2016), although the stranded skeletons could have come from farther afield. Sea fangles were collected in January and February 2015, and processed at Plymouth University on 9$^{th}$ March 2015. To assess the nature and variety of the sea fangles, sea fangles with a minimum of one sea fan amongst a tangled pile of marine litter were selected (Chesil Beach n=30, Wembury n=15 and Newquay n=30). Each sea fangle was photographed, weighed, measured (length and width) and dissected so that each entangled gorgonian and pieces of marine debris could be measured and identified. If there was a central gorgonian skeleton that the rest of the bundle was tangled around, then its length and width was measured and any peripheral gorgonians were counted and weighed. It was also noted whether holdfasts were present (Table S1 in the supporting information lists of the metrics taken to describe to nature of the sea fangles).

*Data analysis*

For each location and each metric the mean, standard deviation, maximum value and minimum value were calculated and summarised in Table S1. The measured debris were grouped into two source categories 'Fishing' or 'Domestic'. A two-factor Permutational Multivariate Analysis of Variance (PERMANOVA+) in the software package PRIMER v6 (Anderson 2001; Clarke & Warwick 2001) was used to compare the fixed factors Source (Fishing or Domestic) and Location (Chesil Beach, Wembury or Newquay). To ensure data independence for the analysis, the Fishing debris data was used from half of the sea fangles, and the Domestic data was used from the remaining gorgonians. Data were untransformed and based on Euclidean distance. To assess which fishing gear types entangled the seafans in each location the mean and standard deviation of each fishing gear type for the three locations were plotted on a bar chart.

## Results

During the surveys in 2015, hundreds of strandings of *Eunicella verrucosa* were observed at each location investigated around southwest England. Almost all of the tangled bundles of marine debris contained a central dead, black or brownish skeletal remains of *E. verrucosa* (Chesil Beach = 83 %, Wembury = 86 %, Newquay = 90 %). The sea fangles were made up of a diverse array of marine litter from fishing and domestic sources (Figures 3) and most of the gorgonians still had a holdfast (Chesil Beach = 76 %; Wembury = 100 %; Newquay = 52 %).

*Sea fangle size and composition*

The weight of each sea fangle varied from 12.2 - 819.2 g, and their size varied from 12.0 - 77.5 cm long and 6.0 - 43.0 cm wide. The height of the central gorgonian within the sea fangle of marine litter varied from 7.5 - 27.2 cm. In addition to the central gorgonian, up to 46 additional small gorgonians were found within the sea fangles (see supporting information Table S1 for sea fangle metrics). There was a wide variety of domestic items found tangled around the gorgonians (i.e. balloons, tights, clothes, plastics, metals and glass fragments), although the amount of debris from fishing was significantly greater than from a domestic source (Figure 4: $P < 0.05$; Table 1).

While a significant Source x Location was detected, this was a result of the magnitude of difference between debris Source at each Location rather than direction of differences. The amount of fishing vs. domestic debris in the sea fangles was consistently significantly greater at each Location (Wembury, Newquay, and Chesil Beach (Figure 4: $P < 0.05$; Table 1).

At all sites, the following categories of fishing debris were observed; Monofilament, Gill net (fine), Trawl net (thick), Fishing line (other) and Rope. Similar lengths of each fishing debris source were observed entangled in the Chesil Beach sea fangles, Gill net was the most abundant category in the Wembury sea fangles, while Monofilament was most abundant in sea fangles washed up at Newquay (Figure 4).

*Evidence of 'Ghost Fishing'*

Over the past decade, divers have often encountered plastic fishing gear amongst living coral gardens on rocky reefs off coasts of southwest England (Dr Keith Hiscock and Chris Wood Seasearch *pers. comm.*; ES & JHS *pers. obs.*). Fishing line and other marine debris such as plastic bags have become snagged and subsequently overgrown by *E. verrucosa* (see Figure 6). Evidence of *E. verrucosa* overgrowing fishing line was also observed during the sea fangles analysis (Figure 3e). When colonies are broken, e.g. through being severed by fishing line, the corals then lay flat on the seafloor and eventually die; the pink or white outer coenenchyme rots leaving the black internal skeleton visible.

**Discussion**

Demersal trawls and dredges have well documented major adverse impacts on long-lived sessile organisms (Rinsjorp *et al*. 2016). Damage to corals by towed demersal gear has expanded enormously over the past 100 years, substantially altering benthic habitats (Koslow *et al*. 2001). Trawling damages coral gardens by reducing the complexity of habitats that they provide to fishes for feeding, breeding and shelter (Mortensen *et al.* 2005; Söffker *et al.* 2011; Sheehan *et al.* 2013). Fishing lines and gill nets also cause damage to deep water gorgonians by abrasion, they can rip the colonies from the seabed or ensnare them when gear is lost or it has been abandoned (Mortensen *et al.* 2005; Bo *et al.* 2014; Lastras *et al.* 2016). However, this effect has not been documented for the shallow water and protected species *Eunicella verrucosa*.

The reason why the gorgonian *E. verrocosa* can be found in high abundances off southwest England is that it grows on rocky reefs, many of which are inaccessible to towed demersal gear (Hinz *et al.* 2011; Pikesley *et al.* 2016). Even on reefs that are heavily impacted by towed demersal gear, e.g. on low lying mudstone, there can be crevices within the complex rocky habitats in which gorgonians persist (Hinz *et al.* 2011) just as patches of gorgonians can still be found in inaccessible rocky canyons off Maine (Auster *et al.* 2013). Further, *E. verrucosa* can also grow on lower lying rock covered in a sediment veneer when the habitat is protected from demersal towed gear (Sheehan *et al.* 2013b). If such areas can be protected effectively, then the corals that survived fishing gear impacts in refugia can provide brood stock for the recovery of coral gardens (Pikesley *et al*. 2016).

Pink Sea Fans entangled with marine debris described here could have formed after gorgonians were detached from the seabed, for example due to damage from gill nets, and then pick up debris as they travel along the seabed with the currents. In addition to the direct damage from fishing, this study shows that ghost fishing may also be responsible for some sea fan mortality. Litter from fishing was the main source of material wrapped around the sea fangle samples that were collected around southwest England. The increased drag of rubbish accumulating around the live gorgonians would make them more vulnerable to removal from their anchorage to the sea floor, particularly during storms. Divers reported that fishing gear was wrapped around live gorgonians and gorgonian skeletal tissue was found here growing over plastic fishing line (Figure 5), which shows examples of when fans become entangled when they are still growing. ‘Ghost fishing’ usually describes the process whereby lost or abandoned gear continues to catch commercial species but it can also cause mortality in gorgonians (Matsuoka *et al*. 2005; Brown & Macfadyen, 2007). Ghost fishing here also applies to lost domestic marine litter, as many household items were found wrapped around the Pink Sea Fans such as clothing, balloons and plastic.

The cumulative effects of lost fishing gear are an ever-growing problem since most modern fishing gear is made of non-biodegradable plastic: materials such as monofilament netting and polypropylene twine accumulate on the seafloor and this can damage long-lived sessile marine organisms (Brown & Macfadyen, 2007; Bauer *et al*. 2008). Impacts can occur when large numbers of recreational anglers lose hook-and-line gear, as this can adversely affect the health and survival of sessile invertebrates causing tissue abrasion in gorgonians (Asoh *et al*. 2004; Chiappone *et al*. 2005; Lewin *et al*. 2006). Injury from tissue abrasion via monofilament line and other fishing gear causes infection and disease in tropical corals (Mydlarz *et al*. 2006). Lamb *et al*. (2015) found four-fold higher levels of coral disease outside no-take marine reserves on the Great Barrier Reef that they attributed to the abundance of derelict fishing gear outside the reserves.

While fishing gear explains most of the sea fangle composition, there was a huge variety of marine debris from domestic sources. Reducing the amount of litter that enters the marine environment would be a valuable step towards mitigating damage to coral gardens. Further, following designation, investment should be directed towards activities to clean up MPAs of existing marine debris. “On the 2nd of October 2016 the UK prime minister pledged to leave the European Union by spring 2019, and that EU law will be transposed into domestic law, wherever practical” (BREXIT) (Jackson *et al.* 2016). Currently, The EU Marine Strategy Framework Directive outlines management steps required to improve the marine realm including that “Properties and quantities of marine litter do not cause harm to the coastal and marine environment” by 2020 (Council of the European Communities, 2008).

Fishing gear is the second largest source of beach litter washed ashore in the UK after public waste, with 106.2 km of fishing nets and net pieces picked up in voluntary clean-up operations in 2015 (Marine Conservation Society 2016). Such clean-up operations can be difficult and costly, for example the Korean Government funded projects to remove marine debris including beach clean ups, removing drifting debris from the sea surface, and then moving offshore and into the deep sea to remove derelict fishing gears (Cho, 2011) and in Hawaii divers have been employed to systematically remove derelict fishing gear (Donohue *et al*. 2001). This study highlights the importance of countries adhering to the EU MSFD marine litter guidance and demonstrates the need for more ambitious regulation which could be created if the UK re-write existing legislation following BREXIT. Beach clean-ups and citizen education can also contribute to stopping debris entering the seas, and fishing closures can be effective at reducing damage from both mobile and static gear, as well as reducing marine litter and promoting coral habitat recovery within the regeneration areas (Harter *et al.* 2009; Lamb *et al*. 2015).

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**Tables**

Table 1. a) Results of PERMANOVA to compare the amount (L mm) of the debris Source (Fishing or Domestic) between Location (Chesil Beach, Wembury or Newquay) b) Pairwise test between Source at each Location. Bold types denotes a statistically significant result

| a) Factor | DF | SS | MS | F | P | b) Pairwise | T | P |
|---|---|---|---|---|---|---|---|---|
| Source (So) | 1 | 9.58E+06 | 9.58E+06 | 47.62 | **0.0001** | Chesil Beach | 2.63 | **0.0001** |
| Location (Lo) | 2 | 2.43E+06 | 1.22E+06 | 6.04 | **0.004** | Wembury | 2.19 | **0.004** |
| So x Lo | 2 | 2.02E+06 | 1.01E+06 | 5.02 | **0.009** | Newquay | 5.32 | **0.0001** |
| Residual | 68 | 1.37E+06 | 2.01E+05 | | | | | |
| Total | 73 | 2.77E+06 | | | | | | |

## Figures

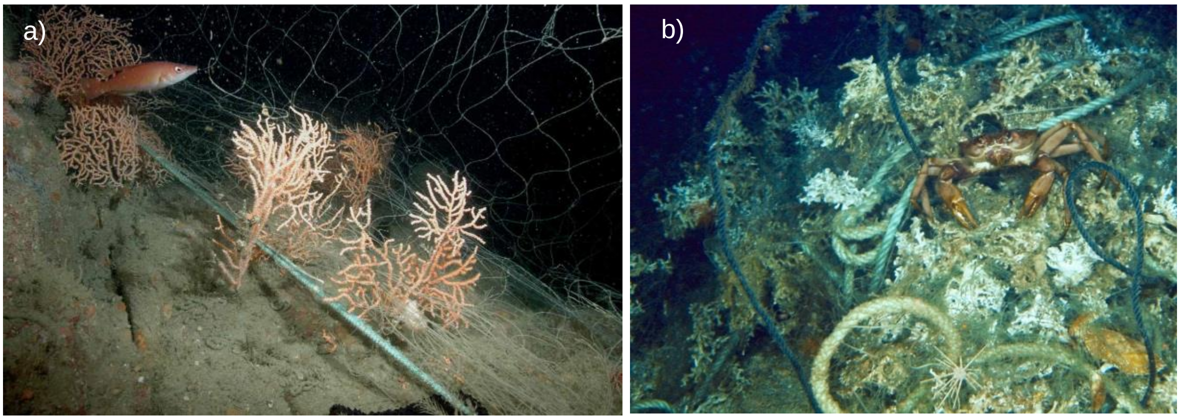


Figure 1. a) Bottom set monofilament plastic gillnet running through a *Eunicella verrucosa* coral garden on bedrock at 20 m depth off Plymouth, southwest England with a female cuckoo wrasse *Labrus mixtus* top left (photo courtesy of Keith Hiscock) and b) a reef constructed by scleractinian and stylasterid corals damaged by non-biodegradable lost fishing gear at 1000 m depth off southwest Ireland with a crab (*Chaceon* sp.) feeding on invertebrates within the smashed-up reef (photo taken by IFREMER owned ROV Victor 2000 aboard RV Polarstern during a study by Söffker *et al*. 2011).

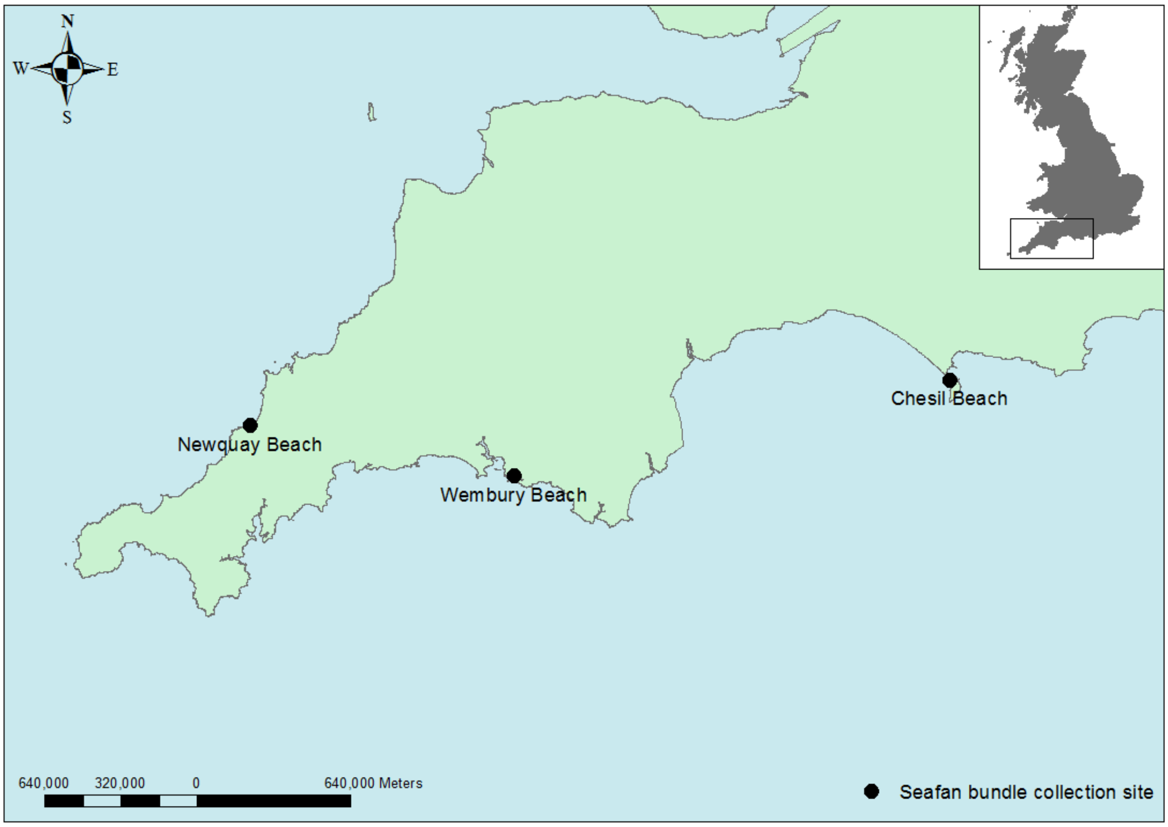


Figure 2. Strandline survey sites at Chesil Beach, Wembury and Newquay in southwest England.

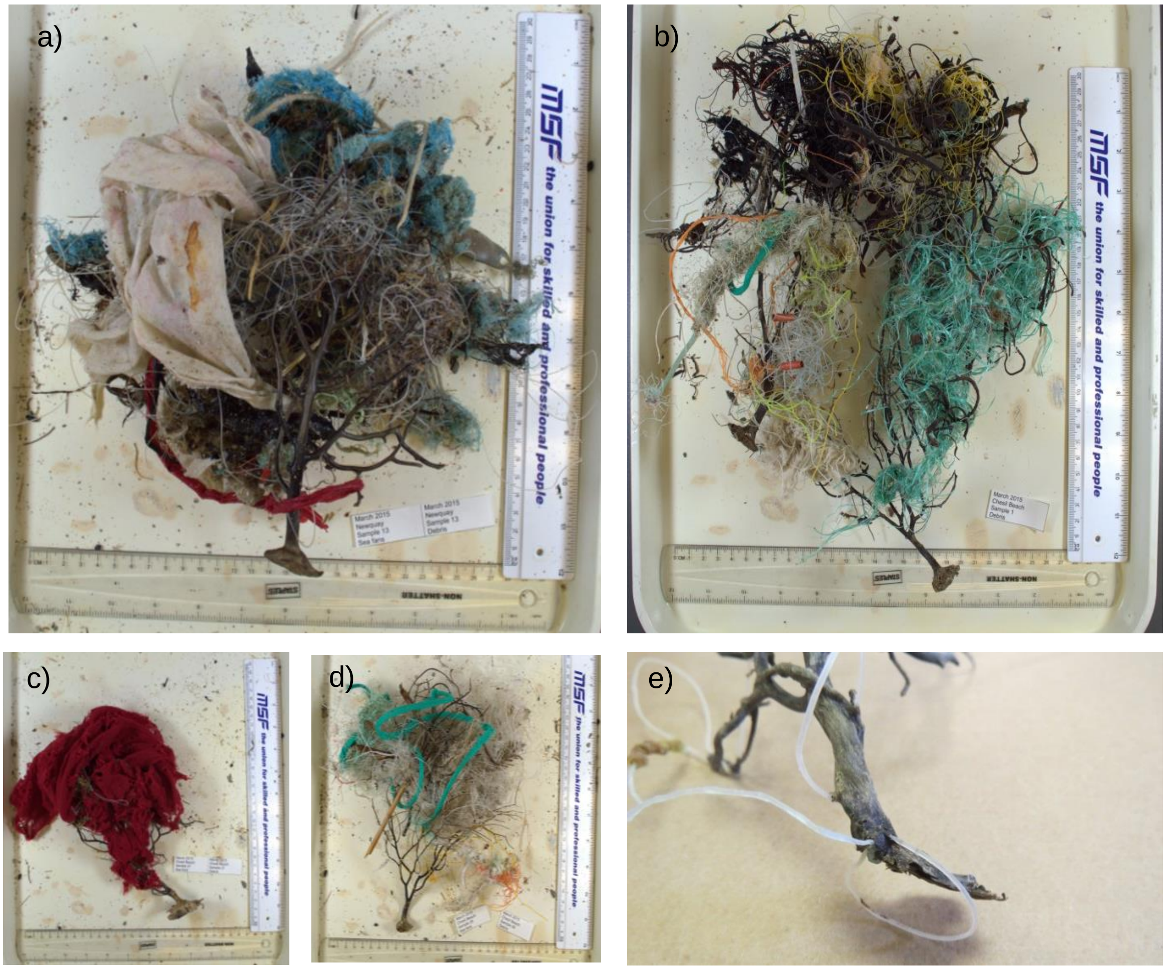


Figure 3a-e) Variety of sea fangles (marine debris wrapped around *Eunicella verrucosa* analysed in the laboratory (rulers 30 cm long). b) monofilament line overgrown by the gorgonian skeleton of *E. verrucosa,* collected from Chesil Beach in January 2015.

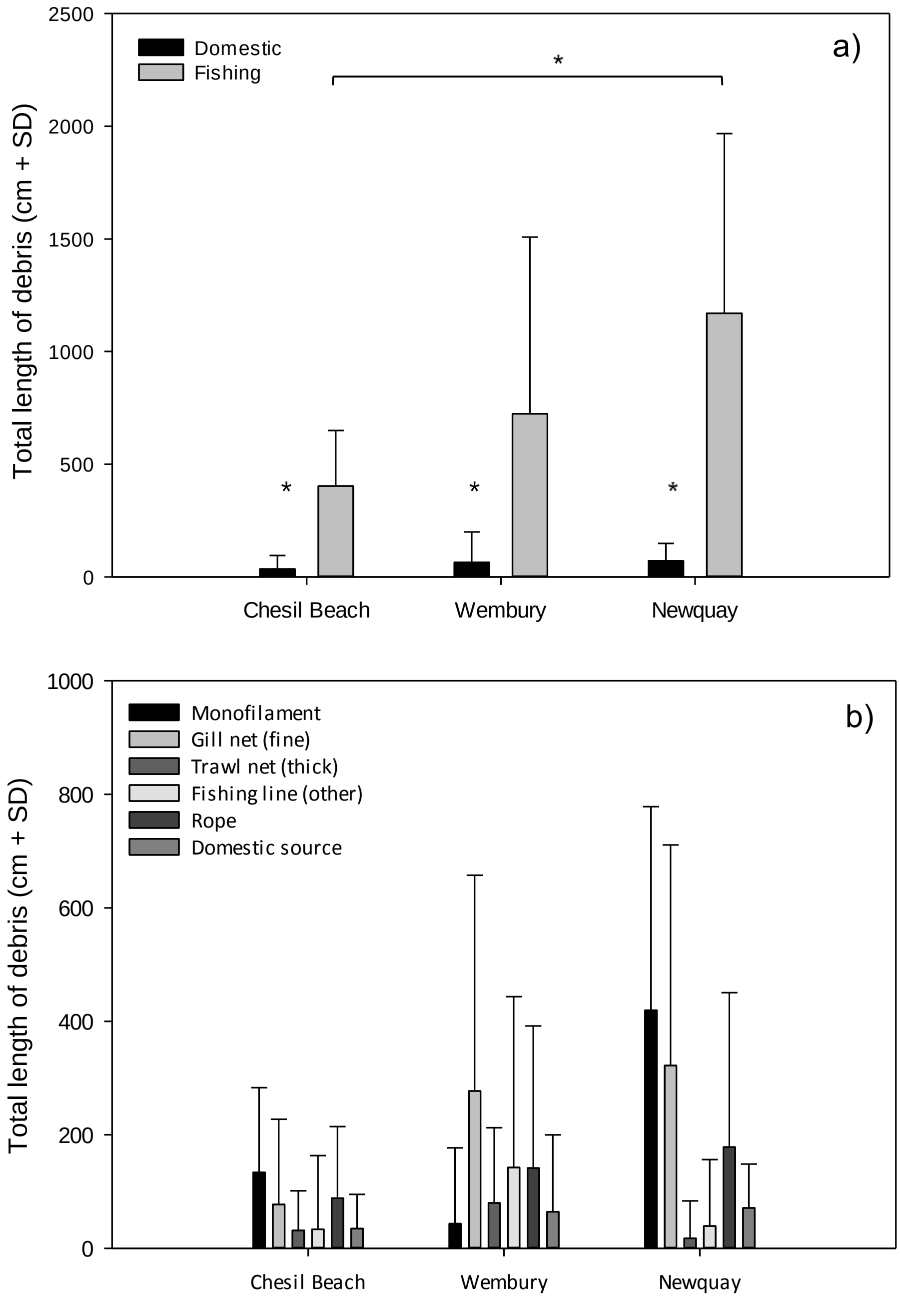


Figure 4 a) Total length (cm + SD) of fishing and domestic debris per sea fangle sampled at three locations around southwest England (Chesil Beach, Wembury and Newquay). * denotes statistically significant difference. b) Total length (cm + SD) of different types of fishing gear and domestic debris per sea fangle.

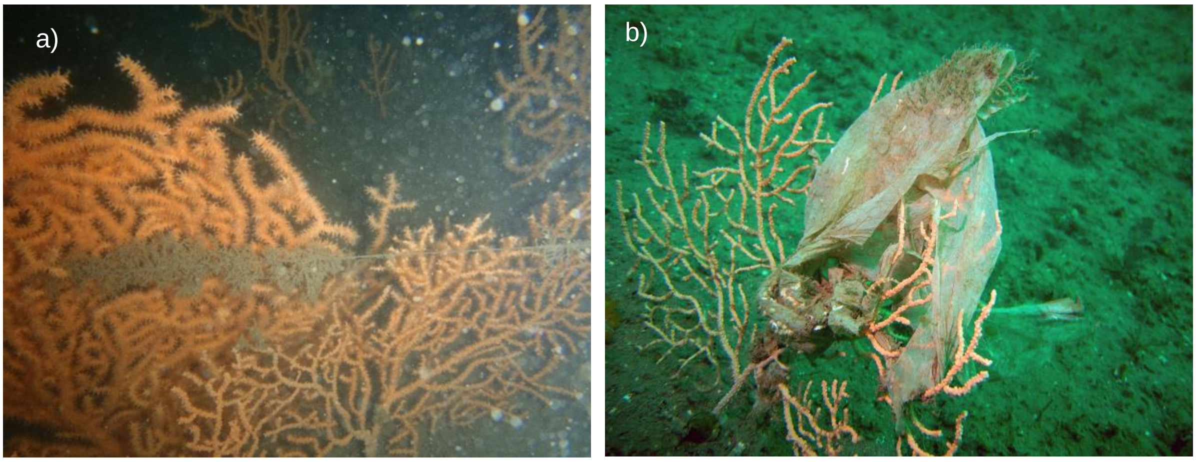


Figure 5a) Fishing line caught on living *Eunicella verrucosa* colonies forming a coral garden habitat on silty rocks (Photo courtesy of William MacLennan, 2014) and b) a living *E. verrucosa* wrapped in a plastic bag (Photo courtesy of Chris Wood/Seasearch, 2007), both images recorded at ~24 m depth in Lyme Bay (off Chesil Beach site) in southwest England.

**Supporting information**

Table S1. Metrics recorded for *Eunicella verrucosa* individuals found within sea fangles collected at three sites around southwest England in January and February 2015.

| **Sea fangle collection site (number collected)** | Chesil Beach (n=30) | | | | Wembury (n=15) | | | | Newquay (n=30) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Metric** | **Mean** | **SD** | **Max** | **Min** | **Mean** | **SD** | **Max** | **Min** | **Mean** | **SD** | **Max** | **Min** |
| Weight of sea fangle (g) | 100.5 | 80.8 | 310.7 | 12.2 | 204.8 | 236.3 | 819.2 | 12.4 | 176.8 | 170.5 | 680.4 | 15.0 |
| Weight of all seafans (g) | 18.1 | 17.8 | 73.5 | 0.9 | 34.2 | 39.0 | 145.0 | 1.3 | 22.0 | 23.3 | 114.6 | 0.8 |
| Length of sea fangle (cm) | 37.4 | 15.4 | 76.0 | 12.0 | 36.4 | 18.4 | 77.5 | 15.0 | 29.2 | 15.2 | 72.0 | 10.0 |
| Width of sea fangle (cm) | 18.9 | 7.6 | 43.0 | 6.0 | 19.6 | 4.6 | 27.5 | 13.9 | 18.9 | 7.9 | 35.0 | 7.5 |
| Central seafan Height (cm) | 16.1 | 3.9 | 27.2 | 10.0 | 14.0 | 4.7 | 26.0 | 8.4 | 15.3 | 16.2 | 15.0 | 7.5 |
| Central seafan Width (cm) | 10.7 | 4.2 | 18.0 | 2.0 | 10.8 | 4.3 | 19.0 | 5.8 | 10.9 | 6.9 | 40.0 | 3.1 |
| Number of fans on periphery (with holdfasts) | 3.1 | 3.9 | 16.0 | 0.0 | 6.1 | 7.6 | 26.0 | 0.0 | 2.4 | 2.9 | 13.0 | 0.0 |
| Number of fans on periphery (without holdfasts) | 1.9 | 2.2 | 10.0 | 0.0 | 10.8 | 11.3 | 37.0 | 0.0 | 6.7 | 8.9 | 46.0 | 0.0 |